Resource Replacement Alternatives Involving Constructed Reefs in Southern California

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1.0 Introduction

The objective of this report is to evaluate the effectiveness of using constructed reefs for replacing or providing substitutes for natural resources injured as a result of exposure to contaminated sediments in marine waters in the area of the Palos Verdes Peninsula.

Constructed reefs involve the creation of hard-bottom habitats in the marine environment, usually along the open coast but sometimes in estuaries or harbors. Constructed reefs are typically placed on sandy substrates. The amount of sand habitat covered depends on the size and design of the reef, with quarry rock reefs having a relatively large footprint while prefabricated reefs typically have a smaller footprint.

In this report, I review the general benefits and technical feasibility of constructed reefs and the relationship between the resources on constructed reefs and the injured resources. Constructed reefs can encompass a wide variety of different materials, designs and locations. To illustrate how these variables can be adjusted to achieve different objectives, I discuss three hypothetical reef projects that could be used to replace injured resources.

2.0 Technical Feasibility and Benefits of Constructed Reefs

Constructed reefs have been used for centuries to enhance fishing. Over the past 15 years or so, there has been increasing recognition that constructed reefs could be used to replace aquatic resources that have been lost due to anthropogenic impacts (Swanson et al. 1978, Stephens and Palmer 1979, Sheehy 1981, Grove 1982, Spanier and Pisanti 1983, Thum et al. 1983, Sheehy 1985, Sheehy and Vik 1985, Ambrose 1986). Constructed reefs have been used or proposed as mitigation for impacts to estuaries, bays or harbors (Alevras and Edwards 1985, Davis 1985, Duffy 1985, Feigenbaum et al. 1989, Lindeman 1989), seagrass beds (Calinski and Whalen 1987, Thorhaug 1989) and rocky habitats (Hueckel and Buckley 1986, Hueckel et al. 1989, Cheney et al. 1994, Cummings 1994). In the United States, reefs have been used for mitigation in several locations, including Delaware Bay (Sheehy and Vik 1992), Chesapeake Bay (Feigenbaum et al. 1989), Washington (Hueckel et al. 1989), and Florida (Davis 1985). In California, mitigation reefs have been built in Long Beach Harbor and San Diego Bay. In addition, the Pendleton Artificial Reef was constructed to test the feasibility of using a constructed reef for mitigation (Grove 1982, Ambrose and Anderson 1989). The largest mitigation reef in the United States has recently been required as mitigation for impacts to a kelp forest caused by the San Onofre Nuclear Generating Station (Ambrose 1990, 1994, California Coastal Commission 1991, Parry and Ambrose 1993), with construction scheduled to begin in 1995.

2.1 Technical feasibility

Hundreds of constructed reefs have been built in the United States, with thousands more elsewhere in the world, so there is little doubt about the technical feasibility of building a constructed reef. In Southern California, more than a dozen reefs have been built from quarry rock (Lewis and McKee 1989), although concrete rubble and vessels have also been used. There are few technical problems with using quarry rock. Careful preconstruction geotechnical surveys are required to guard against the rock sinking into the substrate, but this has been a rare situation in California to date (Dennis Bedford, California Department of Fish and Game, *personal communication* 1994).

The typical Southern California quarry rock reef is a simple rockpile, which is easily constructed by bulldozing quarry rocks off of a barge. Other designs, perhaps even something as simple as a single layer of rocks on the bottom, might present greater technical challenges that would increase the cost of construction.

In addition to quarry rock, there are other viable materials for constructing reefs, including concrete, steel, and fiberglass-reinforced plastic (FRP). Grove et al. (1991) report that concrete and steel are the most commonly used materials in Japan, with "polycon" (a mixture of cement, sand, iron and waste polyethylene) and fiberglass-reinforced plastic also being satisfactory materials. Concrete has been the second-most popular material for reef construction in California, probably because it is durable and often available for free (as scrap from construction projects and the like). There has been much less experience with other materials in Southern California. Prefabricated fiberglass-reinforced plastic (FRP) reefs have been pioneered and used extensively in Japan (Grove et al. 1989, 1991). Comparisons of different materials have been conducted by Sheehy (1983), who found that FRP reefs in 30-75 ft of water in Florida aggregated about 10 times as many fish as concrete conduit reefs, and Moffitt et al. (1989), who found that FRP reefs in about 300 ft of water in Hawaii aggregated about the same number of transient fish as concrete reefs, but that the concrete reefs were superior for resident fish species.

Most constructed reefs, at least in the United States, have been placed in fairly shallow water. Constructing reefs in deeper water might require different construction techniques, but no serious technical obstacles are apparent. For example, the Japanese routinely place reefs in 300-400 ft of water (Sheehy and Vik 1982), and Moffitt et al. (1989) report no problems with deploying concrete and FRP reefs at 190-360 ft depths. In addition, the Department of Fish and Game placed a reef ("International Reef", located in San Diego near the Mexican border) constructed from quarry rock (four modules) and an obsolete missile test platform in 165 feet of water in June 1992. The quarry rock modules were constructed by bulldozing the rock off of a barge. The modules are 10-15 feet tall, and similar to the module configuration on shallower reefs (Dennis Bedford, *personal communication* 1994). As with other reefs in Southern California, there has apparently been no problem with these modules sinking into the substrate.

Constructed reefs can be placed on nearly any reasonably flat substrate. Very soft substrates may not be suitable because reef materials can sink into the substrate, although specially designed reefs or site preparation can be used to circumvent this difficulty. Rocky substrates are generally not appropriate because the addition of rock or other reef materials typically would not cost-effectively enhance the value of the habitat. Burial by sediment could be a problem, although it has rarely been observed on existing constructed reefs in California. Sedimentation problems could be minimized by locating a reef near the upcurrent end or outside of a coastal sediment transport cell (see Inman and Frautshy 1966) and away from rivers that might carry substantial sediment loads. In addition to these physical constraints, there are a number of biological and logistical considerations. A depth of 30-60 ft would maximize primary production and perhaps diversity on a reef, although deeper reefs could also be effective at providing replacement resources. Proximity to natural reefs provides an opportunity for easy recruitment or migration of organisms to the constructed reef, although this may be important for relatively few species that have limited dispersal abilities (such as giant kelp and surfperch). Human activities, such as commercial fishing, navigation, and oil production, may conflict with some reef sites.

Using selection criteria similar to that described above, MEC (1989) evaluated the opportunities for locating shallow constructed reefs in Southern California as mitigation for impacts of port development. MEC identified four promising areas within 40 miles of the Ports of Long Beach and Los Angeles ("the Ports"), which is very close to the center of contamination from DDT and PCBs. The two most promising sites were at Paradise Cove, near Pt. Dume in north Santa Monica Bay, and south of Dana Point, near San Clemente. Both of these areas were favored by MEC because they are relatively close to the Ports, are at the upcurrent edge of sedimentation cells and hence are unlikely to experience heavy sedimentation, and there are rocky reefs and kelp beds in the area. The two other primary areas identified by MEC have somewhat greater constraints. Huntington Beach is the site of intense activity, including recreational and commercial fishing, commercial navigation and oil production and transport. Although these activities might make it difficult to choose a site that is acceptable to all of the competing user interests, there is already a constructed reef site here that might be augmented. The Palos Verdes peninsula area (including both Malaga Cove and White's Point) might also experience conflicts with other users, and there is concern that water quality problems might inhibit development of the reef community. The four sites favored by MEC are by no means the only possible sites for a constructed reef in this region, but MEC's study does indicate that there are a variety of suitable sites that are reasonably close to the contaminated area.

Little work has been done to identify potential locations for deeper reefs. There would be numerous siting possibilities if the reefs could be placed on the soft substrate typical of deeper regions in the Southern California Bight. If substrate conditions are more restrictive, a careful analysis would be required to identify suitable locations or site preparation requirements.

2.2 Benefits

Constructed reefs support a diversity of attached organisms (algae and/or invertebrates) and associated fishes. Fish densities are usually higher on constructed reefs than nearby natural reefs (Fast and Pagan 1974, Russell 1975, Smith et al. 1979, Walton 1979, Jessee et al. 1985, Laufle and Pauley 1985, Matthews 1985, Ambrose and Swarbrick 1989). Because constructed reefs attract fish, as can be seen clearly when adult fish are abundant on a reef shortly after it has been constructed, some scientists have been concerned that the reefs could be simply attracting fish rather than contributing to fish production. Much has been written about this "attraction versus production" issue (for review, see Bohnsack and Sutherland 1985), but this phrase is an oversimplification that does not do justice to the complex issue of how a constructed reef contributes to the production of fish and other organisms. There is substantial evidence indicating that constructed reefs both attract fish and contribute to fish production. The contribution of constructed reefs to production of species that remain on the reef throughout their entire lives, such as the gobies *Coryphopterus* and *Lythrypnus*, is obvious. For larger species that can move on or off the reef, the role of constructed reefs has been less clear. However, a variety of observations indicate that fish production is enhanced by constructed reefs. For example, recent quantitative estimates of fish production on a constructed reef in Southern California (Torrey Pines Artificial Reef) were made using several different methods, including mark-and-recapture, feeding observations and gut content analyses (MEC 1991, DeMartini et al. 1994, Johnson et al. 1994). Data for 11 species indicated a production of 650 kg per ha over the seven-month growing season. This rough estimate has many uncertainties, but the data nonetheless demonstrate that fish reside on a constructed reef for a long period of time and feed and grow while on the reef. 9X
Moreover, fish production on the constructed reef was estimated to be about *nine times higher* per unit area than production on the sand bottom, indicating that constructing the reef greatly increased production over what it would have been had the area remained a sand bottom. There is little doubt that constructed reefs provide significant natural resources, and therefore can be effective at replacing injured fish resources.

Although most discussion in the literature has focused on fish production, many other taxa occur on constructed reefs. Algae and invertebrates are frequently abundant on constructed reefs. For example, algae was abundant on most constructed reefs in a survey of constructed and natural reefs in Southern California, although a few new or deep reefs have very little algal cover (Ambrose 1987, Ambrose and Swarbrick 1989). Giant kelp (*Macrocystis pyrifera*) occurred more frequently on natural reefs (70% of the reefs) than constructed reefs (40%). Mean algal height was greater on natural reefs because of the high cover of foliose red algae and kelps. However, much of the difference between natural and constructed reefs may be explained by the depths and locations of the reefs. Overall, the invertebrate assemblages on constructed and natural reefs were quite similar. The cover of sessile invertebrates, particularly bryozoans, and the density of the gorgonian

Lophogorgia tended to be higher on constructed reefs, while anemones, bivalves, the snail *Kelletia kelletii*, and the red sea urchin *Strongylocentrotus franciscanus* had higher densities on natural reefs. Total invertebrate density was not significantly different between the two reef types. Although this survey compared algal and invertebrate assemblages on constructed and natural reefs and did not compare reefs to sand bottom habitats, the results indicate that constructed reefs support substantial primary and secondary production, with total biomass and production rates likely to be much higher than in sand bottom habitats.

Some of the benefits of relatively shallow constructed reefs will differ from the benefits of deep-water reefs. Deep-water reefs would not provide the same level of ecosystem support in terms of primary production by algae that shallow-water reefs would provide. However, deep-water reefs should support invertebrate and fish assemblages. Moreover, deep-water natural reefs are quite rare around the Palos Verdes area, so the contribution to ecosystem support by constructed reefs compared to natural reefs at these depths might be relatively more important. This may be particularly true for fish such as rockfish, where hard substrate may limit populations, and the provision of additional hard substrate through construction of a reef might increase the carrying capacity of the environment for selected species.

Because of the paucity of relevant studies (Cross and Allen 1993), it is difficult to predict the actual benefit provided by deep-water constructed reefs in Southern California. Moffitt et al. (1989) examined fish assemblages on concrete and FRP reefs placed in 190-360 ft of water in the Hawaiian Islands. They found that the deep-water reefs work well as fish aggregators of commercially important fish, and thus could probably be used to increase catches. However, Moffitt et al. concluded that, in that situation, deep-water reefs probably would not provide additional nursery habitat or enhance overall standing stock much by providing new or improved adult habitat. A study of 16 artificial reefs located in 90-360 ft of water in Florida found the highest number of fish on reefs that were shallower than 140 ft (Shinn and Wicklund 1989). In addition, algae and encrusting organisms such as gorgonians, bryozoans, sponges and corals, which were abundant on shallower reefs, were absent on reefs deeper than 140 ft. Shinn and Wicklund attributed the lower fish abundances on deep reefs to the presence of a thermocline at 140 ft, with temperatures of 30°C above that thermocline and 11-19°C below.

The relevance of these studies of tropical deep-water constructed reefs to the situation in Southern California is not clear. Deep-water natural rock habitat in Southern California is considered to be a scarce and valuable habitat. The problem of the thermocline identified by Shinn and Wicklund (1989) is unlikely to be an issue in California. Given the results of studies on shallow-water constructed reefs, it seems likely that the communities on deep-water constructed reefs would be similar to those on natural reefs, but there are little data to evaluate this possibility. It is not known whether deep-water constructed reefs would provide nursery habitat in California, or substantially increase adult fish habitat, but available evidence suggests that they would. Many of the rockfish species found in the Southern California Bight are associated with rocky areas, especially areas of high relief, deeper than 100 ft (Love et al. 1990). Observations of oil platforms (which can be considered to function similar to constructed reefs) and nearby natural rock areas off Santa Barbara County have also revealed rockfish recruitment to the platforms (Love 1991), suggesting that deep-water constructed reefs could enhance recruitment of rockfish.

3.0 Relationship to Injured Resources

In general, the release and deposition of DDT and PCBs off the coast of Southern California has potentially injured sediments, invertebrates, fish, birds and marine mammals (NOAA et al. 1991). Uncontaminated sediments and invertebrates provide an uncontaminated food source for fish, and ultimately for the birds, marine mammals, and humans that feed on the fish. Contamination by DDT and PCBs degrades the sediments and invertebrates and can lead to reproductive impairment and presumably adverse population effects in the organisms that rely on them.

A constructed reef can provide many of the same functions that uncontaminated sediments provide. By providing substrate for algae and invertebrates, a constructed reef can provide a clean (uncontaminated by DDT and PCBs) food source for fish populations. Clean food can be assured by locating the reef away from the contaminated sediments. It may also be possible near the contaminated area because the algae and reef invertebrates do not burrow into soft sediments (which can be more heavily contaminated), but rely more on nutrients and organisms in the water column for feeding and growth. A constructed reef may also provide functions that uncontaminated sediments do not, but which enhance its ability to replace the injured resources. For example, a constructed reef can provide shelter, which may be particularly important for young fish, giving it a greater nursery function than an unconsolidated bottom. Constructed reefs may also alter hydrodynamics near the bottom (Sheehy and Vik 1992), possibly concentrating plankton in a way that makes them more available to foraging fish.

Although the species that occur on a constructed reef are not the same as those that occur on sand bottom habitats, constructed reefs support a diverse and productive community. Even though the reef fish may not be the same species as the injured fish (although kelp bass occurs on reefs), they perform many of the same ecological roles; moreover, the productive algal and invertebrate communities on constructed reefs play an important role in energy transfer and food chain support. Thus, from an ecological perspective the reef community provides many of the same ecological functions as the injured resources, especially ecosystem support.

No deep-water constructed reefs have been studied in Southern California, so the resources they would provide are not known with certainty. Diversity and productivity would likely be lower than shallow-water constructed reefs, largely because the shallow reefs would have abundant algal assemblages. However, it seems likely that a deep-water constructed reef would provide greater diversity and productivity per unit area than the surrounding soft bottom habitat. Deep-water constructed reefs may also be valuable because of the types of resources they provide. A number of ecologically and economically important fish species, particularly rockfish, utilize deep rocky habitats (Cross and Allen 1993). Stocks of these species might be enhanced by deep constructed reefs. Because the reefs would be placed at depths that are similar to the depths of the contaminated sediments, the resources provided by deep reefs would be especially relevant to the injuries.

In addition to its ecological value, a constructed reef would support a variety of human uses, including increased fishing opportunities and most likely increased recreational fish harvesting. Lobsters, which are important for both commercial and sport fishing, are frequently reported at constructed reefs in Southern California. Other fishery species, such as abalone, urchins and crabs, might also be enhanced by constructed reefs. Urchins are actually less abundant on the constructed reefs in Southern California (Ambrose 1987), but the Japanese have constructed reefs specifically to enhance urchin populations (Grove and Sonu 1983). Constructed reefs would also provide non-consumptive recreational activities, particularly for sport divers.

Deep-water constructed reefs, like their shallow-water counterparts, can enhance fisheries production. The International Reef, located in 165 feet of water, has become extremely popular with sportfishing boats, who report excellent catches of sand bass and red rock fish. In addition, substantial catches of kelp bass have recently been reported from the missile test platform portion of the reef. Thus, deep-water constructed reefs could replace lost recreational and perhaps selected commercial fishing opportunities.

4.0 Project examples

In this section, I discuss three examples of possible restoration projects involving constructed reef. These examples represent realistic projects that could be readily implemented with few modifications. All are technically and operationally feasible and would produce benefits that are related to the injuries. These benefits vary among the projects, however, as do the associated costs. The purpose of presenting specific projects is not to propose these as the only suitable constructed reef projects, but to provide an illustration of the range of reefs projects that would be possible.

4.1 Nursery Reef

The potential benefits of constructed reefs are many and varied, and include increased primary production, enhanced benthic algal and invertebrate communities, increased fish production, provision of nursery habitat, enhancement of depleted fish stocks, mariculture, and increased sport or commercial fish harvests. Not all of these benefits necessarily occur with each reef, and in fact different reef designs can be used to target particular benefits. The first example considers a reef that is constructed to provide nursery habitat, that is, habitat that is suitable for newly settled and juvenile fish.

An important aspect of designing a nursery reef is to identify the features of the habitat that enhance fish recruitment and juvenile survivorship. These features will vary depending on the fish species considered. In general, rocky areas support a higher abundance of fish, with refuges provided by the rocks presumed to be important for the survival of small fish. In shallow areas, giant kelp (*Macrocystis pyrifera*) can also be an important feature, particularly for some species such as kelp bass (*Paralabrax clathratus*). In deeper areas, hard substrate is rarer and may play a critical role for the recruitment of a number of species, including species that support important commercial and recreational fisheries (Carlson and Straty 1981, Pearcy et al. 1989, Stein et al. 1992, Krieger 1993).

Although a major objective of this project would be to enhance fish recruitment, it might be possible to maximize other benefits with particular reef designs. For example, a number of rockfish species are associated with high relief reefs (Love et al. 1990), so this design element might be incorporated, particularly for deeper areas.

Project description

The nursery reef would be designed to enhance fish recruitment and survival in both shallow- and deep-water habitats. While fish recruitment certainly occurs on constructed reefs that are isolated on sand plains (Ambrose 1987), recruitment might be enhanced near existing natural reefs. Suitable locations include the Palos Verdes Peninsula, Santa Monica Bay (including the Malibu coastline), and Orange County.

The reef complex would consist of a series of modules extending from water depths of 40-50 ft to 150-300 ft. The overall configuration could be quite flexible and would depend on local topography, but important design features include: (1) encompassing a range of depths to provide nursery functions across many habitat zones (shallow kelp forest, deep-water rock outcrops, etc.); (2) using durable materials, such as quarry rock or prefabricated reef units, for longevity and to allow the incorporation of design features such as low- and high-relief areas; and (3) maintaining a biological connection between the deepest and shallowest areas of the reef by spacing reef units in a way that could facilitate movement of fish to different depths (see West et al. 1994).

The overall size of the constructed reef should resemble the size of natural reefs. Constructed reefs built to date in Southern California are relatively small; even reef areas that cover a large section of ocean floor have relatively little area that is actually rocky. In contrast, natural reefs often encompass many square miles of rocky substrate. For example, the constructed reefs surveyed by Ambrose (1987, Ambrose and Swarbrick 1989) were an average of 5.5 acres, while the natural reefs surveyed were an average of 456 acres. Some reef functions may be affected by size. For example, large kelp beds may be more stable than small beds, large reefs may contain more habitat types than small reefs, and large reefs may be more likely to encompass the full range of dynamic processes (e.g. Dayton et al. 1984) that can be important to reef communities. For these reasons, it may be prudent to construct the nursery reef(s) on the same scale as large natural reefs.

The establishment of clear objectives and performance standards, and long-term monitoring to determine whether the performance standards have been met, would be an integral part of the reef project.

Benefits

The nursery reef would enhance recruitment and survival of rocky reef fish species, including kelp bass and rockfish, which would offset reproductive impairment caused by exposure to contaminated sediments. To the extent that reef fish are limited by habitat availability or shelter sites, the reef would increase fish population sizes. On the shallower modules, the reef might support giant kelp, thereby providing the ecosystem benefits associated with this diverse community. On the deeper modules, the reef could provide benefits to fish assemblages that live at the same depths as the deeper contaminated sediments. The nursery reef would also provide a number of incidental benefits, including increased primary and secondary production, increased fish production, and increased sport and perhaps commercial fishing harvests (including lobsters and finfish).

Costs

The costs associated with this project include permitting and planning, administration, construction, and monitoring.

Construction costs are the best defined. Nonetheless, there are so many possible construction types and reef designs that there is a tremendous range of possible costs for constructed reefs. Costs for quarry rock reefs are fairly well known because of ample recent experience in building quarry rock reefs in Southern California. In 1990, the cost of constructing a quarry rock reef in the area between Dana Point and Oceanside was estimated to be $30/ton installed (Wilson and Lewis 1990). MEC (1993) used an estimate of $43/ton based on information from Connelly Pacific, the major supplier of quarry rock for constructed reefs in Southern California. For estimation purposes, I use $50/ton to account for price increases and differences in transportation costs.

The amount of rock required per acre for a particular reef depends on the reef design. Pendleton Artificial Reef (PAR), a rockpile reef that I consider to be "high relief", has an average maximum height of 13 ft (Ambrose and Anderson 1989). PAR was constructed from 10,000 tons of quarry rock. The rock itself covers 2.5 acres, with the total area of the reef, including the sand area between its eight modules, being about 7.5 acres. A high-relief reef, constructed with a topography similar to PAR but without the sand between modules, would use about 4,000 tons of rock per acre and cost about $200,000 per acre. A 200 acre high-relief reef would therefore cost about $40 million. A lower reef and/or more sand interspersed within the reef would reduce the cost, perhaps substantially. For example, a low-relief constructed reef might cost as little as $30,000 per acre to build (Ambrose 1990). Wilson and Lewis (1990) provide estimates for constructing reefs of different-height modules, ranging from $58,080/acre for one foot high to $348,480/acre for six feet high. Their estimate for a 375-acre reef complex with 164 modules, each 1.24 acres and 3.5 feet high and spaced 60 feet apart, is $40.6 million.

It is uncertain how construction costs might differ for a deep-water reef. Construction of quarry-rock reefs in shallow water does not require special equipment or handling; the rock is bulldozed directly off of the transport barge. The costs would be the same if a similar technique could be used in deep water, and this was the case for the International Reef placed at 165 ft. However, modification of the standard technique to accommodate the deeper location and softer underlying sediment could increase the costs of construction. For example, softer sediments might require more extensive preparation of a foundation to prevent the rocks from sinking into the sediment. It is possible that the particular conditions in deep water might make designed reefs constructed from concrete or FRP more attractive.

The range of possible costs for designed reefs is even wider than for quarry rock reefs. Cost will depend on material and module design, including such elements as height and amount of interior space, and vendor. There are many possible combinations of these element; for example, Grove and Sonu (1983) list 60 different reef products available in Japan. In addition, there is a wide range of possible configurations or module placements; for example, a reef could have modules spaced in a grid pattern or module clusters, and spacing within and between modules or clusters could vary. Finally, a single designed reef could incorporate several different materials or module designs, including quarry rock. In general, the initial construction costs of designed reefs are likely to be comparable to or somewhat more expensive than quarry-rock reefs.

Assuming the nursery reef would consist mainly of low-relief modules with scattered high-relief areas, construction costs would likely be in the $20 million range for a 200-300 acre reef. Permitting, planning and administration would probably add about 20% ($4 million) to the construction costs, and monitoring would cost approximately $5 million, for a total cost of approximately $29 million.

4.2 Shallow-water Constructed Reef with Kelp Forest

The second project would be a constructed reef to enhance shallow-water reef communities. One goal of this project would be to create a kelp forest on the reef. Although the project would provide suitable replacement resources without giant kelp, the benefits would be increased by the occurrence of a kelp forest community because kelp forests are one of the most valuable marine habitats in Southern California. Compared to the vast expanses of sandy habitats (or even kelpless hard bottom habitats) in Southern California, kelp forests are relatively rare (Ambrose et al. 1989). Kelp forests support an abundant and diverse community (North 1971, Foster and Schiel 1985). Giant kelp (*Macrocystis pyrifera*) is harvested commercially, and there are large recreational and commercial fisheries for many species of fishes, lobsters, abalone and sea urchins that live in kelp forests (North and Hubbs 1968). Giant kelp plants almost always attach to a hard substrate (Foster and Schiel 1985), so most attempts to create new kelp beds have relied on providing new hard substrate. Thus, it is not surprising that constructed reefs have been viewed as possible means of increasing the areal extent of kelp beds in Southern California.

There have been a number of attempts to create new kelp beds on constructed reefs in Southern California. Despite all the constructed reefs that have been built and all the attempts to establish kelp on constructed structures and natural substrates, very few new, self-sustaining kelp beds have been created in Southern California. There have been numerous instances where giant kelp has grown on constructed reefs or other man-made structures (such as outfall pipes), but these typically have been fairly short-lived, with the exception of the kelp bed established on the Los Angeles Harbor breakwater in 1977 (Rice 1983, 1987). There is considerable uncertainty involved in any attempt to create a new kelp bed (or restore a past one). However, even in the absence of giant kelp, this project would still provide all of the benefits of any constructed reef.

One approach to reduce the uncertainty of kelp forest creation is to locate the new kelp bed close to an existing bed. This approach has been taken by the California Coastal Commission in establishing guidelines for Southern California Edison's kelp forest creation project (Parry and Ambrose 1993). Creating a new bed in close proximity to an existing bed should enhance the colonization of the new area by kelp and other kelp forest species.

Project description

The shallow-water enhancement reef would be designed to support a stable kelp forest. Design parameters related to supporting giant kelp would not compromise the reef's benefits if kelp is not established. However, careful consideration of the requirements of giant kelp will increase the likelihood of supporting this species. The key to the successful establishment of kelp is likely to be reef location. The reef must be located in appropriate depths for kelp recruitment and growth, and it should be close enough to existing kelp beds to be easily colonized by giant kelp and other kelp forest organisms. Suitable locations include the Palos Verdes Peninsula, Santa Monica Bay (including the Malibu coastline), and Orange County. Because of its proximity to the contaminated sediments, I have focused on the Palos Verdes region.

The shallow-water enhancement reef would consist of quarry rock placed on sand bottoms near existing kelp forests. Suitable locations include Abalone Cove, east Point Fermin and Malaga Cove. The rock would likely be configured into modules or an irregular cover of the bottom, so that the reef area would consist of rock interspersed with sand. If located within a cove, the entire cove would not be covered in order to avoid interference with possible existing functions of the cove (e.g., nursery areas for flatfish). Because habitat heterogeneity often leads to higher species diversity (for general relationship: Ricklefs 1990, p. 750; for marine fish: Luckhurst and Luckhurst 1978, Helvey and Smith 1985), a variety of reef heights and rock sizes might be employed. The exact design would be refined at the time of construction based on the most current information on physical factors influencing the success of kelp. (For example, recent reports that kelp is more successful on low-relief substrates [Patton 1992] need to be confirmed, and considerable work is currently being conducted on the SONGS mitigation reef.)

As with constructed reefs in general, the size of the shallow-water enhancement reef should resemble the size of natural reefs. However, the size of the shallow-water enhancement reef(s) will also be determined in part by site-specific constraints. For example, approximately 100 acres would be available for kelp forest in the area east of Point Fermin, and approximately 140 acres would be available in Malaga Cove.

Benefits

The shallow-water enhancement reef would contribute substantially to the production of coastal resources. Giant kelp and the variety of organisms that are associated with it would occur in areas that were previously without kelp. Kelp forest fishes such as kelp bass would recruit to and grow on the reef. The shallow-water enhancement reef would also provide other benefits, including increased primary and secondary production, increased fish production, and increased recreational and commercial fishing harvests.

As noted above, there is some uncertainty about whether a stable kelp bed will become established on a constructed reef. Certainly, the presence of giant kelp provides enhanced resource values. However, the value of this reef is not dependent on the establishment of a kelp forest; as discussed above, constructed reefs without kelp provide a wide range of benefits.

Costs

As with constructed reefs, the costs of this project include planning and permitting, administration, construction and monitoring. These costs would be virtually identical to the costs for constructed reefs, with the main difference resulting from differences in reef design associated with maximizing the chances of establishing giant kelp. The cost estimates are based on a relatively high-relief reef, such as typically constructed by the Department of Fish and Game in Southern California; however, if new information about the optimal design for supporting giant kelp indicates that a lower relief is preferred, construction costs would be reduced.

In addition to these general costs, creating a kelp forest on a constructed reef would potentially involve the cost of actively trying to establish kelp. The cost of creating a new kelp bed depends, of course, on the techniques and intensity used to establish the kelp. On the one hand, no extra effort may be required. Some scientists believe that the effort spent transplanting giant kelp to a constructed reef is wasted, since kelp will eventually establish itself if the conditions on the reef are suitable. On the other hand, it may be desirable to attempt to establish the bed as soon as possible in order to minimize the net loss of resources; in this case, substantial costs can be incurred. Active kelp forest establishment is typically very labor intensive. The cost of constructing and deploying the anchors used for kelp attachment in a kelp forest restoration project in Santa Barbara County was $1500 per hectare; fastening juveniles to anchors and then deploying them cost $3,000 per hectare, or $1200 per acre (C. Barilotti, Kelco Co., *personal communication* in Schiel and Foster [1992]). Kelco's costs at Santa Barbara County would translate to $250,000 for 200 acres. However, the techniques used by Kelco on the sand-bottom in Santa Barbara County are probably considerably less expensive than the techniques required on a rocky substrate. The traditional transplantation techniques, which require a great deal of diving, might cost as much as $15 million for 200 acres over and above the cost of constructing a reef. Less labor-intensive techniques such as outplanting early life stages could reduce this cost substantially.

The actual total cost of this project depends on the specific area covered. If Malaga Cove and the area east of Point Fermin are used, as discussed above, then the kelp bed would be created on approximately 240 acres of sand bottom. The constructed reef would consist of rock interspersed with sand, so the rock might cover half of the overall reef footprint. At $250,000 per acre, construction costs would be in the $30 million range. Planning, permitting and administration would add 20% ($6 million) to construction costs and monitoring would cost approximately $5 million, for a total cost of approximately $41 million. Initially, it would probably not be necessary to use active methods of kelp bed establishment. However, if kelp did not become established naturally and studies suggested that active establishment efforts might rectify the problem, establishment techniques could be employed, increasing the total cost of the project to approximately $56 million.

4.3 Fishing Platform Enhancement

The third project coordinates constructed reefs with recreational fishing on public piers or barges. It differs from most previous uses of constructed reefs to enhance fishing success in that fishing does not take place directly on the reefs, but rather the reefs serve as a relatively protected "source" for fish that move to the fishing area. The state of Washington has combined constructed reefs with recreational fishing piers to enhance recreational fishing opportunities (Buckley 1982). Enhancement structures (including automobile-tire modules, scrap concrete and rubble rock) are located either under public fishing piers or outside of a 70-90 ft perimeter around the pier to minimize gear fouling and to provide habitat for sand-bottom fish species. The enhancement areas cover about 5 acres, a far larger area than can be fished from the piers. The strategy was to make 20-30% of the enhanced area accessible to pier anglers, with the remaining area serving to build reserve populations of resident and semiresident fishes to replenish removals by the pier fishery. The enhancement complexes around piers are closed to all other fisheries. In essence, this management strategy provides a harvest refuge, albeit a relatively small one and one that is adjacent to intense fishing pressure.

<u>Project description</u>

(1) navigation probs (boat landings @ pier)

The constructed reefs would be used to increase fish production and catch at existing fishing piers or platforms in Los Angeles and Orange Counties. Production would be enhance by providing complex hard substrate; the reef material could be quarry rock or prefabricated modules. Because the goal would be to increase fish production rather than simply attracting fish, the reef should be relatively large (on the order of 5 acres), and it should be placed far enough from the pier to preclude direct fishing on it. Alternatively, some material could be placed directly underneath the pier. In either case, the reef would be designed so as not to threaten the structural integrity of the pier by increasing scour; in fact, the reef might provide a protective role.

(2) tombolo or other sand movement probs...

These fishing platform enhancement reefs could be placed many of the fishing piers and platforms in Southern California. In general, these piers are located on a fairly flat sand plain, with ample area for a constructed reef, and there is a high likelihood that the constructed reef would increase the productivity of the area. Candidate structures include Santa Monica Pier, Venice Pier, Manhatten Beach Pier, Hermosa Beach Pier, Redondo Sportfishing Pier, Belmont Shores Pier, Annie B. Barge in Long Beach, and Seal Beach Pier.

Benefits

The fishing platform enhancement reefs would increase the production of reef fish in an area where reef fish are relatively uncommon. Higher recruitment, growth and survival of rocky reef fish species would be expected to lead to larger fish stocks. The enhanced stocks would be comprised primarily of reef fish, although flatfish densities might also be enhanced (Walton 1979). As with other constructed reefs, algae and invertebrate populations would also be enhanced (see Hueckel 1980). In addition to ecosystem benefits such as increased production, the fishing platform fish enhancement reef would provide improved recreational fishing opportunities. The fish species that would be caught due to constructing reefs around fishing piers differ from the species upon which the lost fishing opportunities are based. These fish would likely have lower body burdens of DDT and PCBs because they would feed mainly on reef organisms or the organisms near the reef. In addition, they are generally more highly prized than the fish species that are most commonly caught from piers (e.g., mackerels and croakers).

Costs

The costs of constructing a reef near fishing piers would be roughly the same as for constructed reefs in general, although there would be some additional costs related to avoiding problems from scouring around the pier structures. A quarry rock reef would cost $50,000 to $200,000 per acre, depending on the height of the reef and the amount of sand interspersed within the reef. Constructed reefs around fishing piers might be considerably smaller than nursery or shallow-water enhancement reefs, perhaps on the order of 5 acres. A rough estimate would therefore be $1 million for a 5-acre reef. Larger reefs would cost proportionately more.

Navigation? (whale watching, fishing boats)

Why not enlarge existing groins, etc for fishing?

Richard F. Ambrose, Ph.D.

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